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Genetic Variation in Douglas-fir: A 20-year Test of Provenances in Eastern Nebraska

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Abstract

Twenty-year-old Douglas-fir trees in provenances from Arizona, New Mexico, and southern Colorado survived better and grew taller; but incurred more winter injury in eastern Nebraska than trees from provenances from northern Colorado, southern and western Montana, northern Idaho, Canada, and eastern Washington. However, surviving trees from Pacific Coast, and northern and central Rocky Mountain provenances increased in percent of plantation mean height during the past 9 years, whereas trees from southern Rocky Mountain provenances decreased. Age/age correlations indicate provenances expressing superior height growth can be identified at age 6.

Acknowledgements

The diversity of tree planting materials under study at this and other locations in the Great Plains was made possible through cooperation with the Regional Tree Improvement Project (NC–99) of the North Central States Agricultural Experiment Stations. Credits are due Jonathan W. Wright, Professor of Forestry, Michigan State University (deceased) for initiating this regional study and providing the planting stock; and to Ralph A. Read, Silviculturist (retired), and John A. Sprackling, USDA Forest Service; and Walter T. Bagley, Associate Professor of Forestry (retired), University of Nebraska, for planting, maintaining, and evaluating the early performance of this species.

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Management Implications

Douglas-fir is a conifer species that is not indigenous to the Great Plains. However, it has been planted sparingly and in selected locations, mainly as an ornamental, throughout the central Great Plains for many years. Interest in its use for Christmas trees has increased in recent years.

Identification of seed sources of Douglas-fir that are adapted to the central Great Plains environment could increase its use, reduce planting failures, and add to the number and variety of conifer species available to forestry agencies and commercial nurseries for windbreaks, Christmas trees, and environmental and esthetic plantings within the Great Plains—a region in which few conifer species are native.

Cautionary Statement

Heavy mortality in the nursery and during the first year of field establishment imposed severe limitations on the analysis and interpretation of 20-year-old Douglas-fir provenance data. Numbers of individuals in some provenances, particularly those of northern origin, were reduced drastically. Also, individual trees in some provenances have declined in vigor during recent years.

Despite these limitations, the overall performances of the surviving individuals in the majority of provenances have been consistent over the past 20 years. This is the only test of Douglas-fir in the central Great Plains and, thus, the sole source of data relating to the adaptability of Douglas-fir to this region. Therefore, it is deemed appropriate to report these data for their use in improving initial care and establishment procedures, and in the selection of seed sources in future tests.

Introduction

Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco), the variety of primary concern in this study, occurs in most of the western mountain ranges east of the Coast Range in British Columbia and east of the Cascades and Sierra Nevada Ranges in the United States (Ryker and Steele 1980). Specifically, it is widely distributed in central British Columbia, southwestern Alberta, eastern Washington, Oregon, Idaho, Montana, Wyoming, southeast Arizona, and southern New Mexico; and locally in the mountains of northern and central Mexico (Little 1971, 1979) (fig. 1).

Coast Douglas-fir (*P. m.* var. *menziesii*), of which two provenances are represented in these data, occurs along the Pacific Coast eastward into the Cascade Mountains from southwestern British Columbia, through western Washington and western Oregon to central California; and in the Sierra Nevada to central California and western Nevada (Little 1971, 1979) (fig. 1).

Rocky Mountain Douglas-fir grows at elevations from 1,200 to 8,000 feet in the Northwest on a wide variety of soils and parent materials including granitic, volcanic, sedimentary, and metamorphic (Pfister et al. 1977). As Douglas-fir approaches its warm, dry limits (below 6,000 feet) towards the Great Plains, it becomes more restricted to basic soil parent materials such as andesite, basalt, and limestone (Ryker and Steele 1980); the latter type commonly occurs throughout the Great Plains region.

The plantation reported on here at 20 years of age, is part of a larger test of Douglas-fir provenances for which 1-year-old nursery and 3- to 8-year-old field data in Michigan and Nebraska plantations were reported (Wright et al. 1971). Eleven-year field performances of the provenances in this Nebraska plantation were reported by Read and Sprackling (1976). The objective of this study was to identify adapted sources of Douglas-fir for planting in the central Great Plains.

Materials and Methods

Seedling stock for the Nebraska plantation originated from 55 of 128 bulked sources of Douglas-fir seed assembled from native stands throughout the species range in the United States and Canada (Wright et al. 1971). The seeds were sown in an East Lansing, Mich., nursery in 1962; the seedlings were distributed to cooperators in 1963. The Nebraska seedlings were lined-out for 2 years before field-planting.

Small seedling size, a heavy-textured soil, and lack of protection from sun in the summer and protection from wind in the winter, in the Nebraska line-out beds, resulted in a 90% loss of seedlings over all provenances (97% within the Pacific Coast origins, 95% within the northern Rocky Mountain origins, and 71% within the central and southern Rocky Mountain origins) (Read and Sprackling 1976). Of the original 14 Pacific Coast provenances, only 22 seedlings of 6 provenances survived; of the 26 northern Rocky Mountain provenances, 56 seedlings of 19 sources survived; and of the 15 central and southern Rocky Mountain provenances, 187 seedlings of 13 provenances survived for field planting (Read and Sprackling 1976).

Surviving seedlings were field-planted in the spring of 1965 on a ridgetop of silt-loam, in single-tree, complete-

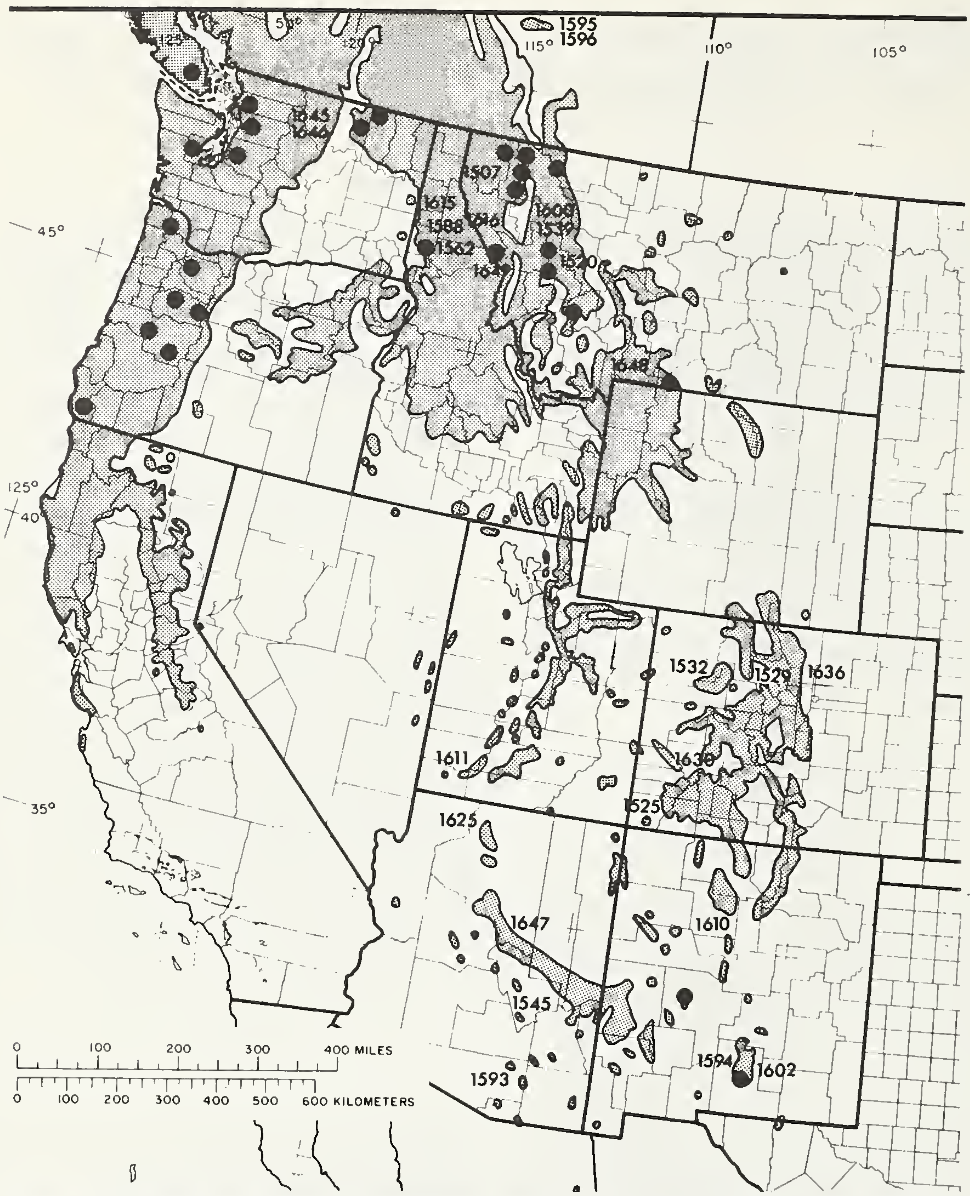

Figure 1.—Natural distribution of Douglas-fir, and provenances tested in eastern Nebraska. Numbers denote origins that survived; black circles, those that died in the nursery, or during first year after field planting (Read and Sprackling 1976).

ly randomized plots, spaced 12 feet apart in rows 12 feet apart. Unequal numbers of seedlings among the provenances precluded adherence to the intended randomized complete block design; thus, the seedlings were planted according to a completely randomized design. An eastern redcedar (*Juniperus virginiana* L.) seedling was planted between each Douglas-fir seedling, in the row, to provide early protection; they were removed in 1974 to avoid crowding.

Poor survival complicated the analysis of these 20-year data and, therefore, placed restrictions on any derived inferences. Several provenances were represented by a single tree and others by fewer than 10 trees, thus giving poor estimates of survival proportion. Additionally, several provenances had been replanted, and there was no within-plantation structure to the experimental design. Survival was not analyzed statistically in view of these limitations.

Analysis of variance ($P = 0.05$) and an unequal-sample-size multiple range test were applied to evaluate tree height growth. Significant variation was indicated among provenances; however, the multiple comparison test was sufficient to statistically detect only differences between the very tallest and the very shortest trees. Toward a goal of a more interpretable analysis, the provenance means were partitioned into groups with similar heights by a cluster analysis method (Scott and Knott 1974). Unlike a multiple range test that would identify pairwise differences in height growth among provenances, the cluster analysis method identifies group centers in a way that maximizes between-group variation (or equivalently, minimizes within-group variation). Similar to analysis of variance, significance of a particular partition of the provenances is assessed by comparing between-group vs. within-group estimates of variance with an adjustment of the latter to incorporate

the residual variance estimated in the initial analysis of variance. The data are clustered into successively larger numbers of groups until between- and within-group estimates of variance are not significantly different ($P = 0.05$). The result is a nonsubjective partitioning of the provenances according to their height, which can be evaluated for geographic pattern. This analysis provides no information about differences between individual provenances, but it does assess the significance of differences between the centers of groups of provenances.

Phenotypic age/age correlations were computed at the tree and provenance levels for provenances with 3 or more trees of record and all provenances.

Results and Discussion

Survival

As Read and Sprackling reported (1976), in 1975, 11 years after field-planting, 77% of the seedlings of the 6 Pacific Coast provenances, and 61% of the seedlings of the 19 northern Rocky Mountain provenances had died. Only two Pacific Coast provenances (1645 and 1646) and 12 northern Rocky Mountain provenances had any survivors, with numbers per provenance ranging from 1 to 7 (table 1). No provenances from the central and southern Rocky Mountains were lost; but, mortality of seedlings averaged 37% and 11% in the central and southern provenances, respectively. Virtually all seedling mortality occurred during the first year in the field. Losses were attributed to heat and drought during the summer and to dessication of foliage in the winter on the relatively exposed ridgetop site.

In the 11-year analysis, Read and Sprackling (1976) clearly demonstrated the necessity of protecting Douglas-fir seedlings in the nursery and during early years in the field. They attributed the high mortality in the nursery to lack of shading and protection from wind during extremely hot and cold weather, and lack of moisture at critical times during the growing season.

Ryker and Potter (1970) demonstrated that shaded Douglas-fir seedlings survived more than twice as well (70% vs. 30%) as unshaded seedlings in field plantings. Shading reduces solarization, a process in which photosynthesis is inhibited by high light intensities (Ronco 1970).

In 1984, after 20 years in the field, numbers of trees per provenance ranged from 1 to 34, leaving 178 trees in 27 provenances (table 1). Only 1 tree, from provenance 1525 (s.w. Colo.), had succumbed during the 9-year period (1976–1984) following the 11-year evaluation. Surviving trees numbered 5, 22, 43, and 108 in the Pacific Coast, northern, central, and southern Rocky Mountain provenances, respectively (table 1).

These data indicate that, once established, Douglas-fir can survive in the eastern part of the central Great Plains to age 20; and that under the conditions of this test, the central and southern Rocky Mountain sources have survived best. There is indication, however, that some sources, especially those of southern origin, may not maintain this survival advantage. Observations in the spring of 1986 revealed a decline in the vigor of some trees. Eight of 11 trees exhibiting decreased vigor (3 in 1532, and 1 each in 1526, 1611, 1625, 1545, and 1593) occurred in the southern portion of the species range. One tree each in the northern Rocky Mountain and Pacific Coast provenances 1588, 1596, and 1645 also showed a decline in vigor. Nonadaptability of individual genotypes to the matrix of environmental variables in the Great Plains probably explains this occurrence.

Height

Read and Sprackling (1976) reported that the seedlings, after becoming established in the field, grew at a mean annual rate of 1.4 feet from 1968 to 1975 (range 0.4 to 1.9 feet), and averaged 12.8 feet in height after 11 years (table 1). Variation in annual growth within the northern Rocky Mountain group was 33% (0.4 to 1.2 feet per year). Adaptive differentiation occurs in Douglas-fir across relatively small environmental gradients, of which there are many and steep (elevational) clines throughout northern Idaho, western Montana, and Canada. Thus, a moderately wide range of variation might be expected from within that region (Rehfeldt 1984).

Average tree heights among provenance groups (Read and Sprackling 1976) were tallest in the southern Rocky Mountain group (14.8 feet) and shortest in the northern Rocky Mountain group (6.9 feet) (table 1). Within the northern Rocky Mountain group average tree heights ranged from 3.4 to 10.1 feet. This pattern of taller growth in the southern provenances is reflected in the "percent of plantation mean" data, where percentages of 116 in the southern Rocky Mountain vs. 54 in the northern Rocky Mountain provenances were attained. Individual provenance means ranged from 140% in the Arizona provenance 1593 (Mt. Lemmon) to 27% in the Montana provenance 1648 (Big Timber) (table 1).

The relatively good height growth of the few surviving trees in the two Pacific Coast (central Washington) provenances, compared to the average height of trees in the northern Rocky Mountain provenances is of interest. The survival of these few provenance trees, originating from an arid sector of central Washington, seems explainable on a genetic basis. Douglas-fir populations characteristically possess a high degree of genetic diversity (Rehfeldt 1979, 1984). Given this diversity, any given generation produces some genotypes that are preadapted to environmental conditions outside the tolerance of the parental generation. Those individuals able to survive in the Nebraska environment, are most probably those individuals whose genetic constitutions can tolerate the extremes of the new (Nebraska) environment. The small number of trees surviving may be explained on the basis that the greater the distance from the source of origin, the smaller the number of preadapted genotypes capable of surviving in the new environment.

The clustering procedure (Scott and Knott 1974) used to analyze the 20-year results utilized height data from 14 of the 27 provenances, all of which had 3 or more surviving trees. Trees that had been replanted as seedlings

Table 1.—Twenty-year performances of surviving Douglas-fir trees of 27 provenances in an eastern Nebraska test.[1]

Michigan State Univ. No.	Origin of Seeds: State or Provenance	Origin of Seeds: Locale	Latitude	Longitude	Elevation	Survival: Planted 1965	Survival: Survived 1975	Survival: Survived 1984	Height: 11-year	Height: x̄ annual	Height: 20-year	Height: x̄ annual	Plantation mean height: 1968–75	Plantation mean height: 1975–86
			°N	°W	ft.	no.	no.	no.	ft.	ft.	ft.	ft.	%	%
Pacific Coast (var. *menziesii*)														
1645	WA	Fish Lake	48.6	119.7	2,000	7	4	4	10.4	1.1	22.8	1.2	81	93
1646	WA	Buck Mountain	48.4	119.8	5,000	5	1	1	8.9	1.1	22.0	1.3	70	90
				Subtotals and means		12	5	5	9.6	1.1	22.4	1.2	75.0	91.8
													+16.8	
Northern Rocky Mountain (var. *glauca*)														
1615	ID	Coeur d'Alene	47.7	116.8	2,400	3	2	2	9.2	1.1	23.5	1.4	72	96
1588	ID	Wallace	47.5	116.0	3,000	9	7	7	8.8	1.0	22.3	1.4	69	91
1562	ID	Clarkia	47.0	116.1	4,500	5	2	2	4.5	0.5	17.5	1.3	35	72
1507	MT	Libby	48.4	115.5	3,800	1	1	1	9.8	1.2	24.0	1.4	77	98
1600	MT	Spotted Bear RS	48.0	113.0	3,680	1	1	1	6.4	0.8	20.0	1.4	50	82
1616	MT	St. Regis	47.5	115.2	4,000	4	3	3	10.1	1.2	22.3	1.2	79	91
1649	MT	Missoula	47.0	114.0	3,500	2	1	1	8.0	0.9	22.0	1.4	62	90
1520	MT	Greenough	46.9	113.4	4,000	4	1	1	9.5	1.1	26.0	1.6	74	107
1539	MT	Big Prairie RS	47.3	113.5	4.600	2	1	1	3.6	0.4	13.0	0.9	28	53
1595	AB	Kananaskia	51.0	115.0	4,500	2	1	1	5.7	0.7	19.0	1.3	45	78
1596	AB	Kananaskia	51.1	115.0	5,000	4	1	1	4.2	0.5	15.0	1.1	33	61
1648	MT	Big Timber	45.5	110.0	6,000	5	1	1	3.4	0.4	14.0	1.1	27	57
				Subtotals and means		32	22	22	6.9	0.8	19.9	1.3	53.9	81.6
													+27.7	
- - - - - - - - - - [2]														
Central Rocky Mountain (var. *glauca*)														
1636	CO	Boulder	40.2	105.5	8,650	14	7	7	8.6	1.0	21.3	1.3	67	87
1529	CO	Kremmling	40.0	106.5	8,000	5	2	2	9.0	1.0	22.0	1.3	70	90
1532	CO	Meeker	40.2	107.9	8,200	28	21	21	9.5	1.1	21.7	2.1	74	89
1630	CO	Ouray	38.2	107.6	9,100	3	1	1	11.4	1.3	27.0	1.6	89	111
1525	CO	Durango	37.5	107.8	8,500	12	8	7	12.7	1.4	24.6	1.2	99	101
1611	UT	Panguitch	37.6	112.5	8,250	5	5	5	9.7	1.4	20.6	1.1	76	84
				Subtotals and means		67	44	43	10.2	1.2	22.9	1.4	79.7	93.8
													+12.1	
Southern Rocky Mountain (var. *glauca*)														
1610	NM	Jemez RD	35.5	106.8	8,500	29	28	28	14.9	1.6	26.0	1.1	116	107
1594	NM	Cloudcroft	33.0	105.8	8,670	11	8	8	15.1	1.7	27.0	1.2	118	111
1602	NM	Mayhill	32.9	105.4	7,000	37	34	34	15.7	1.7	26.8	1.1	123	110
1625	AZ	Fredonia	37.0	112.5	9,000	12	9	9	10.7	1.2	20.9	1.0	84	86
1647	AZ	Long Valley	34.7	111.0	7,000	12	12	12	14.0	1.5	25.0	1.1	109	102
1545	AZ	Globe	33.3	110.7	7,800	5	4	4	15.6	1.6	24.2	0.9	122	99
1593	AZ	Mt. Lemmon	32.4	110.8	8,400	14	13	13	17.9	1.9	28.5	1.1	140	117
				Subtotals and means		120	108	108	14.8	1.6	25.5	1.1	115.6	104.5
													−11.1	
Plantation totals and means						236	178	177	12.8	1.4	24.4	1.2		

[1] *Extension of table in Read and Sprackling (1976).*
[2] *Performance data above dashed line is less reliable because of limited number of trees.*

did not materially influence the mean provenance heights in 1981 or 1984; thus, they were included in the analysis.

Two significantly different groups were identified in the analysis: a southern group (sources 1525, 1545, 1593, 1594, 1602, 1610, and 1647), with a mean height of 26.0 feet; and a mixed group (sources 1532, 1588, 1611, 1616, 1625, 1636, and 1645), with a mean height of 21.7 feet (fig. 2). Tree height, computed with provenance means, was significantly ($P = 0.02$) and negatively correlated ($r = -0.61$) with latitude; correlation with elevation was weak ($r = 0.21$). Subtle, but noticeable changes have occurred since the 11-year analysis when considering all provenance performances, regardless of numbers of surviving trees. Trees in provenances from the southern Rocky Mountains continue to be the tallest ($\bar{x}$ = 25.5 feet), followed by central Rocky Mountain ($\bar{x}$ = 22.9 feet), Pacific Coast ($\bar{x}$ = 22.4 feet), and northern Rocky Mountain ($\bar{x}$ = 19.9 feet) provenances. However, 9 years later, there is a change in the relative values of mean annual growth. Trees in the southern Rocky Mountain provenances have decreased in mean annual growth from 1.6 to 1.1 feet, but trees in the northern Rocky Mountain provenances have increased from 0.8 to 1.3 feet per year. The rankings among provenance groups for "percent of plantation mean" have remained the same, but the 1975 vs. 1984 percent of plantation mean values show gains in 1984 of +27.7%, +16.8%, +12.1%, and −11.1% for the northern Rocky Mountain, Pacific Coast, central Rocky Mountain, and southern Rocky Mountain provenances, respectively (table 1). The relative improvement in height growth of the northern provenances over the southern sources is slight but discernible (fig. 3).

The decline in rate of height growth in the southernmost provenances is apparently due to periodic dieback of terminal growth caused by periodic winter injury.

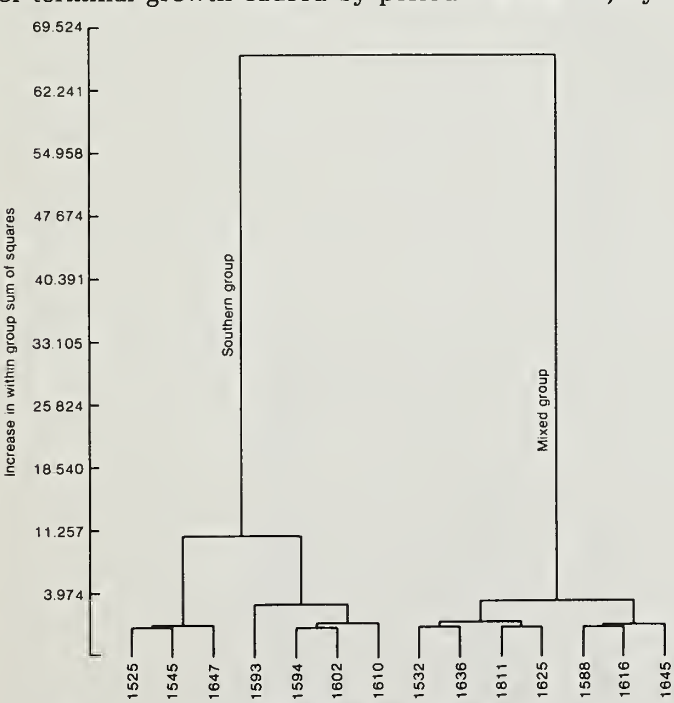

Figure 2.—Height clustering of Douglas-fir provenances

Trees in provenances 1545 (Globe, Ariz.) and 1647 (Long Valley, Ariz.) incurred terminal damage from freezing in 1969, 1971, and in 1981–1984 (fig. 3). The decline in vigor of trees in the central (1525, 1532, and 1611) and southern provenances (1545, 1593, and 1625) may have contributed to the decline in relative height growths. Thus, there appears to be a slight, but perceptible, pattern of increased height growth of the northern provenances relative to southern provenances.

Winter Injury

Winter injury, expressed by the amount of terminal dieback, was evaluated in the present evaluation at age 12 (winter 1976–77). Injury was detected on 1 of 5 surviving trees in the 2 Pacific Coast provenances, and on 1 of 22 surviving trees in the 12 northern Rocky Mountain provenances (table 2). Sixty-seven percent of the trees in the southern Rocky Mountain provenances suffered some terminal dieback, ranging from 49% in the Fredonia, Ariz. provenance (1625) to 100% in the Globe, Ariz. (1545) provenance (table 2). Less injury (16%) occurred in the 6 central Rocky Mountain provenances.

The pattern of injury was consistent with that reported by Read and Sprackling (1976); they found that injury within provenances occurred on the same trees in successive years. Winter injury had not caused the death of any trees; the killed terminals were replaced by one or more lateral branches, one of which assumed dominance (Edgren 1970). Despite repeated dieback of terminals on some trees within the southern provenances, growth each year exceeded the loss of terminal growth occurring at irregular intervals. Exceptions may be the Arizona provenances 1545 and 1647, which appear in doubt of maintaining the growth/loss ratio (fig. 3). Northern provenance trees incur very little winter injury; their shorter heights has been attributed to later initiation of the growth processes in the spring and earlier cessation of the process in the fall (Wright et al. 1971, Campbell and Sorenson 1973).

Susceptibility of the same trees within provenances to incur repeated terminal dieback can be attributed to genetic variability among trees within a provenance locale. The genotypes of such trees, due to adaptive differentiation within provenance microsites, are variable within local populations in their tolerance to the extremes of variation in environmental factors present at the test site (Van Haverbeke 1968, Rehfeldt 1984).

The higher percentages of seedling loss in the nursery among provenances of northern origins compared to lower losses of seedlings among southern origins, seems a contradiction to the relatively higher percentages of winter injury in the field among seedlings of southern origin reported by Read and Sprackling (1976). The relatively smaller size and, thus, perhaps physiologically weaker condition of the northern seedlings while in the nursery, may account for this initial loss.

Age/Age Correlations

Height at age 20 was poorly predicted in all but the most recent measurements when computed at the tree

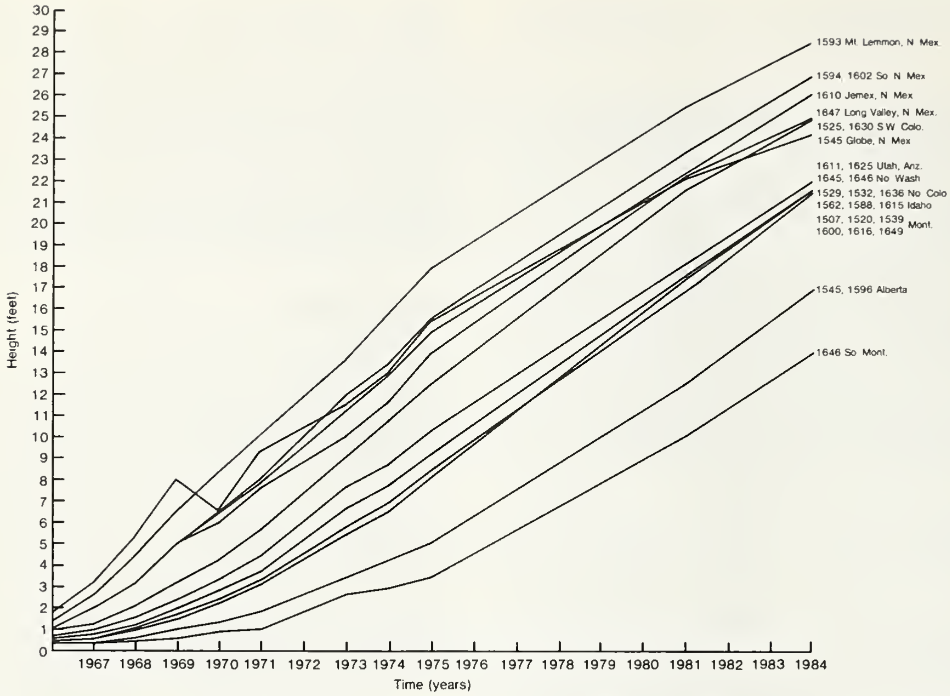

Figure 3.—Height growth curves for Douglas-fir origins (some grouped) after 20 years in an eastern Nebraska plantation (extension of fig. 2, Read and Sprackling 1976).

Table 2.—Winter injury (terminal dieback) in Douglas-fir provenances, winter 1976-77.

Mich. State Univ. Prov. No.	Location	Trees surviving in 1977	Trees damaged	Trees damaged	$\bar{x}$ damage per tree
		no.	*no.*	%	*ft.*
Pacific Coast					
1645	WA	4	1	25	2.0
1646	WA	1	0		
Northern Rocky Mountain					
1615	ID	2	0		
1588	ID	7	1		
1562	ID	2	0		
1507	MT	1	0		
1600	MT	1	0		
1616	MT	3	0		
1649	MT	1	0		
1520	MT	1	0		
1539	MT	1	0		
1595	ALB	1	0		
1596	ALB	1	0		
1648	MT	1	0		
Central Rocky Mountain					
1636	CO	7	0		
1529	CO	2	1	50	1.0
1532	CO	21	4	21	1.0
1630	CO	1	0		
1525	CO	8	1	12	1.0
1611	UT	5	1	20	3.0
Southern Rocky Mountain					
1610	NM	28	20	71	2.0
1594	NM	8	5	62	1.4
1602	NM	34	23	68	1.9
1625	AZ	9	4	49	1.0
1647	AZ	12	7	58	2.4
1545	AZ	4	4	100	4.0
1593	AZ	13	9	69	2.4
Total		178	81		
$\bar{x}$				46	2.2

level. However, phenotypic age/age correlations computed at the provenance level, where the mean was adequately described with 3 or more trees, showed steadily improving values with decreasing time intervals; the indication was that mean provenance height could be adequately predicted at age 6 (1970) (table 3).

Conclusions and Recommendations

Twenty-year performance results are in close accord with those reported at age 11 by Read and Sprackling (1976). Survival data suggest that, in eastern Nebraska, Douglas-fir seedlings will incur heavy mortality in the nursery and during early years in the field unless seedlings are of good quality and are protected from solarization, drought, and winter exposure. These results indicate that well-developed planting stock is necessary to insure field survival; stock of 2 + 1 or 2 + 2 age class, possessing a well-balanced shoot-root ratio, should be planted. Protection can be provided by sheltering seedlings in lath- or shadehouses prior to field planting; and by shielding seedlings individually with "cedar shingles," or by interplanting a faster growing, but temporary "nurse" tree species such as eastern redcedar (*Juniperus virginiana* L.). Avoidance of frost pockets and exposed sites is also advised.

This study found that trees of southern Rocky Mountain origin survive better and are taller after 20 years than trees of most central Rocky Mountain and northern origins. Once established, however, the surviving trees of northern sources persist and, because of lack of winter injury, appear to be slowly narrowing the height advantage gained earlier by the trees of southern sources. Central Rocky Mountain sources are relatively winter hardy and grow quite well; they are recommended for ornamental planting in the eastern part of the central Great Plains. They also may be suitable for establishing windbreaks around farmsteads and in urban plantings where protection and water can be provided. As in the 11-year evaluation, the southwest Colorado provenances 1525 (Durango), and especially the high-elevation provenance 1630 (Ouray), because of its trees of good vigor, continue to be recommended.

Table 3.—Phenotypic age/age correlations computed at the provenance level among ages 2 to 20 for 14 provenances of Douglas-fir.

	Correlations										
Age ------ / Year -	2 1966	3 1967	4 1968	5 1969	6 1970	8 1972	9 1973	10 1974	11 1975	17 1981	20 1984
2 1966		.99	.98	.98	.89	.92	.86	.84	.86	.81	.68
3 1967			1.00	.99	.91	.94	.88	.86	.88	.84	.71
4 1968				1.00	.94	.96	.91	.89	.91	.87	.75
5 1969					.94	.96	.91	.89	.91	.87	.75
6 1970						.99	.99	.98	.99	.98	.91
8 1972							.98	.98	.99	.97	.88
9 1973								1.00	1.00	.98	.93
10 1974									1.00	.98	.94
11 1975										.98	.93
17 1981											.95
20 1984											

Age	Year	Prov.	x̄ height	SD
		no.	*ft.*	
2	1966	14	0.92	0.37
3	1967	14	1.44	0.76
4	1968	14	2.41	1.31
5	1969	14	3.70	1.97
6	1970	14	4.63	1.93
8	1972	14	5.92	2.35
9	1973	14	9.00	2.54
10	1974	14	10.38	2.82
11	1975	14	12.25	3.13
17	1981	14	20.04	2.94
20	1984	14	23.87	2.54

The southern Rocky Mountain provenances incur the most winter injury. However, they recover and are the fastest growing provenances as a group. If adequately protected, provenances 1593 (Mt. Lemmon, Ariz.), 1594 (Cloudcroft, N. Mex.), and 1602 (Mayhill, N. Mex.) are recommended, with caution, for Christmas trees, where short rotations decrease the probability of severe loss during the occasional winter of unusually cold temperatures. The foliage of trees from Arizona and New Mexico also is uniformly among the bluest (Wright et al. 1971)—a desirable Christmas tree characteristic.

In view of the appreciable gain in percent-of-plantation mean (+27.7), (table 1) of the northern Rocky Mountain provenances during the past 9 years, this region should not be overlooked as a source of material of high potential for the central Great Plains. Trees of northern Idaho (1588 and 1615) and western Montana (1507, 1520, and 1616) provenances, although few in number, performed well in this test. They may ultimately prove superior to the above-recommended central and southern Rocky Mountain provenances in terms of survival and height growth. Further testing of Douglas-fir is recommended—appreciating the limitations of funding, the availability of material, and the time required to obtain definitive results. An alternative, assuming adequate seed production, would be to remove the undesirable phenotypes and provenances in the present test and allow the remaining trees to interbreed. Performances of the original provenances would serve as controls. Phenotypic age/age correlations indicated that provenances expressing superior height growth can be identified by age 6.

It is appreciated that the number of provenances and the number of surviving trees in many of the provenances is small—especially in the northernmost provenances. However, the performance patterns among individual trees, provenances, and groups of provenances during the past 20 years has been impressively consistent.

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Twenty-year-old Douglas-fir trees from Arizona, New Mexico, and southern Colorado survived better, grew taller, but incurred more winter injury in eastern Nebraska than trees from northern provenances. Northern trees increased in percent of plantation mean height in past 9 years. Provenances expressing superior height are identifiable at age 6.

Keywords: *Pseudotsuga menziesii* var. *glauca*, *P. menziessii*, provenance, seed source, age/age correlation, winter injury

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Rocky Mountains

Southwest

Great Plains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota
Tempe, Arizona

*Station Headquarters: 240 W. Prospect St., Fort Collins, CO 80526